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UNPUBLISHED PRELIMINARY DATA

April 13, 1965

Technical Reports Officer
Office of Grants and Research Contracts
Office of Space Science and Applications
National Aeronautics and Space Administration
Washington, D.C. 20546

Your ref: SC-NsG-48/33-018-002

Dear Miss Morgan:

<u>Semi-Annual Status Report No. 10 on NASA Grant No. NsG 48</u>

<u>for the period May 1, 1964 - October 31, 1964.</u>

In accordance with NASA specification 25-1, dated October 5, 1964, for the preparation of technical reports this report is hereby submitted in letter format as required for Type I-Progress Reports.

PAPERS PRESENTED

At the 17th Annual Gaseous Electronics Conference, Atlantic City, October, 1964.

J. H. Noon, E. H. Holt and J. P. Quine, Microwave Measurement of the Probability of Collision of Low-Energy Electrons in Nitrogen. Bull. Amer. Phys. Soc. 10, 185, (1965).

ELECTROMAGNETIC WAVE PROPAGATION IN MAGNETOPLASMAS

The metal waveguide cell (Figure 1) constructed in the previous period was tested and its electrical discharge and microwave characteristics were determined. Improvement of the electrical discharge performance was obtained by modifying the construction of the electrode and tuning assemblies at each end of the cell. The final design is shown in Figure 2. A discharge can be successfully operated at pressures from 0.25 to 1 Torr and currents of 5 milliamps. The discharge is quite stable and fills the whole vessel uniformly. However if one electrode and the metal walls are both at ground potential the discharge becomes unstable and the plasma near the electrodes tends to be displaced towards the adjacent walls in spite of the layer of glyptal insulation. With a "floating" DC supply or, for pulsed operation, an isolating transformer, the discharge is quite stable. When a magnetic field is applied the discharge constricts and for a field of 1000 gauss is restricted to the central region with a radius of approximately 1 cm.

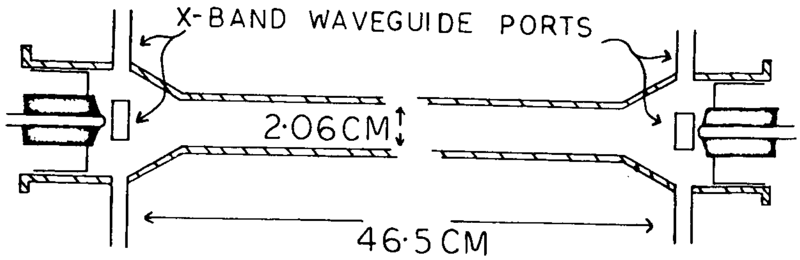

Figure 1. Schematic diagram of the waveguide cell showing the modified turnstile junctions at each end of a length of circular guide.

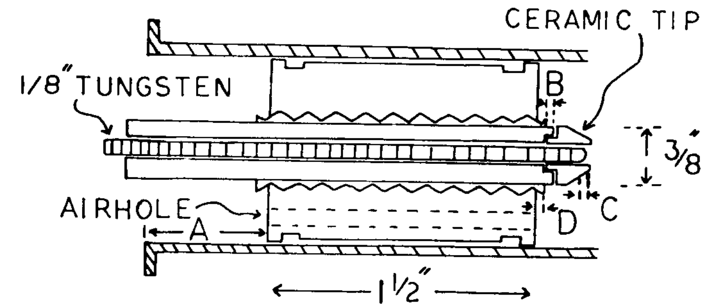

Figure 2.

Schematic diagram of the coaxial metal stub assembly used for microwave matching and in which the inner rod acts as a discharge electrode. For dimensions see Table 1.

End	A	B	C	D
1	2 1/2"	9/32"	3/16"	1/32"
2	1 3/16"	1/4"	1/16"	1/2"

TABLE 1. End Matching Conditions for Turnstile Junctions.

Adjustment of the matching units at both ends was made to give a constant frequency response over as broad a range as possible. This is necessary because the change in dielectric constant of the plasma in a magnetic field alters the effective wavelength of the propagated microwave signal. An X-band sweep oscillator was used to deliver power to the cell and to generate the oscilloscope sweep display of the response of the crystal detectors mounted on the output ports. The dimensions of the components of the matching units when correctly adjusted are shown in Figure 2 and the frequency response of the cell in Figure 3. Within the range 9.4 to 9.8 Gc/s the transmitted signal is constant to within 0.5 db, but drops off outside this range. The reflected power level is more than 30 db below the incident power level. The amount of cross-coupling between adjacent arms represents a power level of <25 db. This should be zero but perfect symmetry of the junctions would be required to achieve this.

Values of the relative output signals at 9.5 Gc/s in arms 1 and 2 for a discharge current of 4 milliamps are shown in Figure 4 for various values of magnetic field. These show the sensitivity of the technique since a large amount of cross-coupling is obtained.

DIFFUSION IN MAGNETOPLASMAS

Diffusion as an Initial Value Problem

In the previous period work was done on the solution of the improved macroscopic diffusion equation appropriate to the initial value problem. In the present period the problem has been carried forward by solving the Boltzmann equation as an initial value problem. The result of this approach is quite general and can be used to discuss the development of any of the macroscopic variables.

The problem of transport variables is directly related to the symmetry or anti-symmetry of the distribution function in velocity space. No flow can result in, say, the x direction if the distribution function is symmetric about the v_x axis.

However, discussion of the even and odd components of the distribution function is somewhat more complex than it might at first appear. We have shown that even in the absence of external forces, the symmetric and anti-symmetric parts are coupled, so that a net flux will arise even if the distribution function is initially isotropic.

In the absence of external forces, the Boltzmann equation takes the form

$$\frac{\partial f}{\partial t} + \bar{v} \cdot \nabla f = \left(\frac{\partial f}{\partial t}\right)_c$$

and for gradients in the x direction only, it becomes

$$\frac{\partial f}{\partial t} + v_x \frac{\partial f}{\partial x} = \left(\frac{\partial f}{\partial t}\right)_c$$

We proceed by splitting the distribution function into odd and even components with respect to v_x, i.e., $f(v_x) = f^o(v_x) + f^e(v_x)$ where $f^o(-v_x) = -f^o(v_x)$ and $f^e(-v_x) = f^e(v_x)$. The equations for $f^o(v_x)$ and $f^e(v_x)$ are

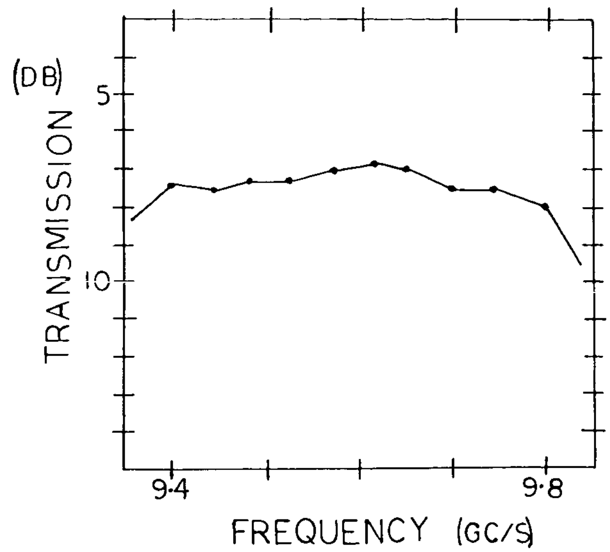

Figure 3.

Transmission characteristics of the cell as a function of frequency.

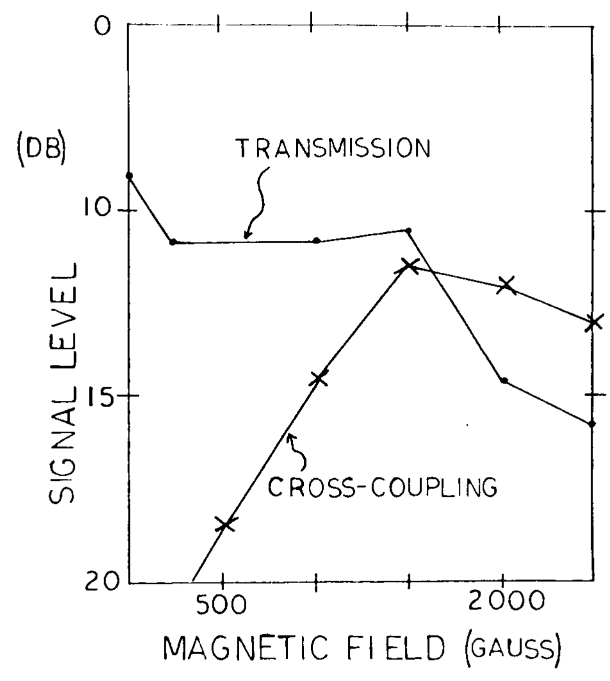

Figure 4.

Signal levels of the two orthogonal output arms for a linearly polarized 9.5 Gc/s input signal passing through the magnetoplasma, as a function of magnetic field.

$$\frac{\partial f^o}{\partial t} + v_x \frac{\partial f^e}{\partial x} = -\nu f^o$$

and

$$\frac{\partial f^e}{\partial t} + v_x \frac{\partial f^o}{\partial x} = 0$$

These equations enable us to solve the Boltzmann equation as an initial value problem. The final solution is

$$f(x,v,t) = e^{-\frac{\nu}{2}t} F(v)\, n(x-vt)$$

$$+ \frac{\nu e^{-\frac{\nu}{2}t}}{2v} F(v) \int_{x-vt}^{x+vt} n(\gamma) \sqrt{\frac{x-\gamma-vt}{x-\gamma+vt}}\; J_1 \left[\frac{\nu}{2}\, \frac{1}{v} \sqrt{(x-\gamma)^2 - v^2 t^2} \right] d\gamma$$

$$+ \frac{\nu e^{-\frac{\nu}{2}t}}{2v} F(v) \int_{x-vt}^{x+vt} n(\gamma)\, J_o \left[\frac{\nu}{2}\, \frac{1}{v} \sqrt{(x-\gamma)^2 - v^2 t^2} \right] d\gamma$$

There are several important aspects of this equation that should be noted. Firstly, it predicts that each velocity class diffuses at its own intrinsic speed. Therefore, a diffusing gas smears out due to a distribution of initial velocities. Secondly, it is essentially a correction to the result of the macroscopic approach. This correction is important if the spread of initial velocities is "large" compared with the "average" speed. A further implication is that "hot" particles diffuse more quickly than "cool" ones. Therefore temperature gradients are immediately set up in a diffusing gas so that it is unrealistic, in general, to disucss density gradients without considering the associated temperature gradients. However, the most important implication of this equation is as follows. In postulating that the pressure was equal to nkT, it was explicitly assumed that the distribution function was factorable into a density in configuration space and a density in velocity space. This equation shows that this is not, in general, true.

Finally, we should note that given the initial distribution function, any macroscopic variable can be determined by taking the appropriate moment of this equation. This approach represents a considerable simplification, as the higher order moments of the Boltzmann equation are usually non-linear and therefore fairly difficult to solve.

THE NITROGEN AFTERGLOW

During the present period the microwave radiometer which was developed under this grant was used to make a detailed study of the energy changes of the electron gas constituent of the nitrogen afterglow plasma. The results are an extension of the previous work of Stotz[1] in this laboratory. The variation of the electron energy in the early afterglow has been studied with the radiometer gating pulse extending into the active discharge region. A typical result is shown in Figure 5 for the first fifty microseconds of the afterglow period. There is a rapid energy relaxation from the electron energy attained in the active discharge, followed by a slower but very marked rise in energy, which subsequently falls even more slowly to the equilibrium value.

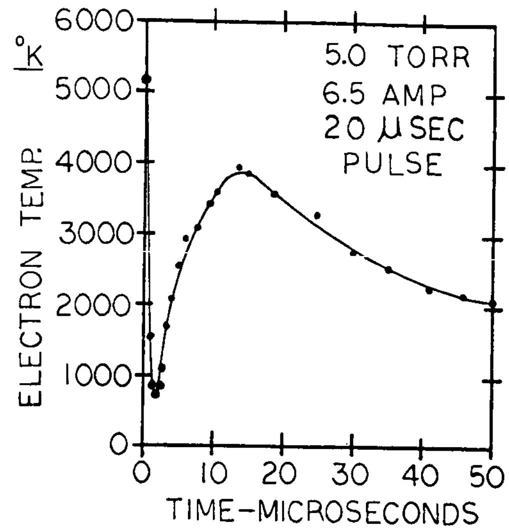

Figure 5. Anomalous Behavior of the Effective Electron Temperature in the Nitrogen Afterglow.

Analysis of the initial, rapid energy relaxation shows that it occurs in the time expected when electron collisions with neutral gas particles are the mechanism of electron energy loss. A relaxation time for the electron temperature can be calculated by writing the average rate of energy loss due to collisions as

$$d\,\bar{u}_e/dt = \lambda(\bar{u}_e - \bar{u}_g)\,\nu_m \qquad (1)$$

where λ is the mean fractional energy loss in collisions, $\bar{u}_e - \bar{u}_g$ is the average excess electron energy above that of the gas molecules and ν_m is the electron-molecule collision frequency.

The mean fractional energy loss, λ , is usually written in terms of the ratio of the masses of the electron (m) and the molecule (M), as $\lambda = G(2m/M)$. The G factor is unity for elastic collisions, but when excitation of low-lying rotational levels of the nitrogen molecule are taken into account G has been reported variously as being equal to 5.5[2] and 20.[3,4] An average value can be obtained from the data of Frost and Phelps.[5]

If, for the moment, we assume that the electron velocity distribution function is Maxwellian then equation (1) can be rewritten in terms of electron temperature. Taking $(\lambda\nu_m)/N$ as 1.5×10^{11} cm^3 sec^{-1}, for a range of electron energies from 0.03 to 0.27 eV, where N is the number density of molecules (cm^{-3}) = 3.2×10^{16} p, and p is in Torr, the rate of decay of electron temperature may be written, using these approximate numerical values, $(dT_e/dt) = -3 \times 10^5\, p\,(T_e - T_g) = d(T_e - T_g)/dt$ and the electron-temperature relaxation time has the form $\tau \approx 3/p$ where τ is in microseconds, p is in

1. K. C. Stotz, NASA TN D-2226, (1963).
2. J. M. Anderson, L. Goldstein, Phys. Rev. 102, 388, (1956).
3. J. C. Bowe, Phys. Rev. 117, 1416, (1960).
4. D. Formato, A. Gilardini, Ionization Phenomena in Gases (Proc. Fifth Internat. Conf.) Vol. 1, p. 660, North Holland, (1962).
5. L. S. Frost, A. V. Phelps, Phys. Rev. 127, 1621, (1962).

Torr. This expression for τ agrees quite well with that given by Mentzoni and Row,[6] and with their experimental results using a mildly driven discharge with a pulsing time of a few microseconds. Our own results are also in agreement at this point. The relaxation time τ may also be interpreted as the relaxation time of the mean electron energy in which case the assumption of a Maxwellian electron velocity distribution is not required.

The form of the electron energy variation in the afterglow is dependent upon the conditions in the active discharge. This is shown in Figure 6 where the electron heating effect is markedly reduced for the shorter pulse length even though the discharge current was considerably increased in order to achieve the same electron energy at the end of the active discharge in both cases. This effect probably accounts for the conflicting values of relaxation times obtained by Mentzoni[6] and by Formato and Gilardini.[7]

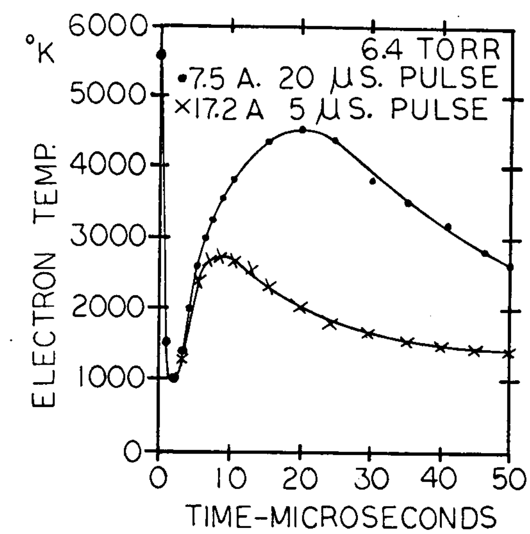

Figure 6. Dependence of the Electron Heating Effect in the Nitrogen Afterglow upon the Active Discharge Conditions.

INSTRUMENTATION

The six-coil Magnion magnetic field system was delivered during the present period. Installation was completed and the unit was used to obtain the performance data on the waveguide cell which was described earlier in this report.

No further work was done on the time-of-flight mass spectrometer.

DISBURSEMENT OF FUNDS

A separate report is submitted by the Comptroller's office.

6. M. H. Mentzoni, R. V. Row, Phys. Rev. 130, 2312, (1963).

7. D. Formato, A. Gilardini, Ionization Phenomena in Gases (Proc. of Fourth Internat. Conf.) Vol. 1, p. 99, North Holland, 1960.

PERSONNEL

Name	Position	Percent Time 1*	2*	3*
E. H. Holt	Professor Senior Investigator	50	75	50
J. H. Noon	Visiting Professor	50	75	50
K. C. Stotz	Assistant Professor	50	(terminated June 5, 1964)	
H. B. Hollinger	Assistant Professor	33	--	25
H. Bayoumi	Graduate Assistant	--	100	(20)
D. A. Huchital	Graduate Assistant	(20)	25	(20)
J. A. Reynolds	Graduate Assistant	--	100	(20)
P. N. Y. Pan	Graduate Assistant	50	100	25
R. M. Quinn	Graduate Assistant	10	100	50
R. Jennings	Graduate Assistant	--	---	25
A. Cohn	Graduate Assistant	--	---	100
A. Ajello	Graduate Student	(20)	---	---
P. Blaszuk	Graduate Student	--	---	(20)

Support Personnel

H. Struss	Research Assistant (model shop)	25	25	50
J. Wright	Electronic Technician	100	100	100
W. Jennings	Student Technician	---	100	25
J. Carroll	Student Technician	20	(terminated June 5, 1964)	
R. Ramachandran	Student Technician	--	100	25
C. V. Bhimani	Student Technician	10	---	--

Note

Figures in brackets indicate participation in the research without charge to the grant.

PLANS FOR THE NEXT PERIOD

A bakeable design for the magnetoplasma cell discussed herein will be completed and construction commenced. The theoretical study of plasma diffusion will continue with the problem of plasma diffusion in the presence of electric and magnetic fields. Work will commence on the design of a cesium plasma cell for the magnetoplasma work. An experimental study using probes will be initiated aimed at investigating the transition from classical to anomalous diffusion in magnetoplasmas. Methods of increased sensitivity for microwave phase measurements in plasmas will be investigated experimentally.

Yours truly,

E. Howard Holt

E. Howard Holt
Professor of
Electrical Engineering

*1. May 1 - June 5, 1964, Academic year 1963-64.

*2. June 8 - September 11, 1964, Summer 1964.

*3. September 14 - October 31, 1964, Academic year 1964-65.